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ALLEVIATION OF THERMAL STRAIN IN ENGINEERING SPACE PERSONNEL ABOARD CF SHIPS WITH THE EXOTEMP PERSONAL COOLING SYSTEM

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EXECUTIVE SUMMARY

In August 1990 the Government of Canada sent a naval task force, including five Sea King helicopters, to the Persian Gulf in support of United Nations activities against Iraq. The Directorate of Maritime Aviation (DMA) requested the Defence and Civil Institute of Environmental Medicine (DCIEM) to provide personal cooling systems to the deployed aircrew to help reduce the thermal stress anticipated in the Gulf region. A commercially available system, developed and built by Exotemp of Pembroke, Ontario, was quickly adapted and integrated into the Sea King operations. It gave the Canadian Forces the first aircrew personal cooling system ever to be used in war and prevented the heat stress that so severely limited the missions of all our allies in the Gulf.

Having heard of the successes of the Exotemp system in the Sea King operations, the Director of Research and Development Maritime (DRDM) tasked DCIEM to investigate the feasibility of using this same personal cooling system to alleviate thermal strain in the engineering space watch keepers who work in chemical defence clothing outside the citadels of the three Canadian ships deployed to the Gulf. Logistics, costs, and risks ruled against a field study aboard HMCS Terra Nova in the Gulf in early January 1991. Instead, a physiological and integration trial took place aboard HMCS Ottawa while en route from Halifax to Puerto Rico during the period 22—26 January 1991. Although HMCS Ottawa is a different class of ship than HMCS Terra Nova, the engineering spaces are essentially the same, and the thermal environment was manipulated to simulate conditions anticipated in the Gulf.

Twelve engine room personnel from three watches participated in the trial, conducting their normal duties while being monitored for physiological thermal strain in four clothing ensembles: normal work dress (**WD**); normal work dress with cooling (**WC**); chemical defence clothing (**CD**); and chemical defence clothing with cooling (**CC**). Rectal temperature results clearly indicated statistically significant benefits of cooling with the chemical defence clothing (condition **CC** vs condition **CD**). Although not statistically significant, reductions in core temperature were also seen when cooling was used with normal work dress (condition **WC** vs condition **WD**). Heart rate data, along with limited skin temperature and heat flux information, corroborated the core temperature findings.

It is concluded that the Exotemp personal cooling system is a viable means of controlling thermal strain in engineering space personnel aboard Canadian ships. With fewer constraints in terms of weight, space, and power, it may be easier to integrate personal cooling systems into ships than into other military vehicles. Most of the engineering space personal cooling requirements could probably be provided via an insulated umbilical to a fixed cold fluid supply, with reliance on the portable cooling packs for those times when personnel must be ambulatory.

ABSTRACT

The engineering spaces aboard Canadian Forces (CF) ships operating in warm climates can become very hot working environments. Some of these areas, notably the boiler room, are outside the citadel, and personnel working in these areas during periods of chemical threat must wear chemical defence (CD) clothing. The extra insulation and the increased resistance to sweat evaporation of this clothing, coupled with the heat of the environment, can impose a severe heat stress on the engineering personnel. A field trial was conducted aboard the HMCS Ottawa while en route from Halifax to Puerto Rico to see if the Exotemp liquid-based personal cooling system, proven very successful in CF Sea King helicopter operations in the Persian Gulf, could alleviate thermal stress under the above simulated conditions. Twelve engine room personnel from three watches participated in the trial, conducting their normal engine-room duties while being monitored for thermal physiological strain in four clothing ensembles: normal work dress (**WD**); normal work dress with cooling (**WC**); chemical defence clothing (**CD**); and chemical defence clothing with cooling (**CC**). Note that the engine room was used in place of the boiler room because it offered more space, and because the environment was easier to control. Heat stress conditions of 45-50°C dry-bulb temperature were created by shutting off the ventilation fans for about 90 minutes at the start of each watch. Rectal temperatures at 90 minutes of elapsed time clearly indicated statistically significant benefits of cooling with the chemical defence clothing (condition **CD**: 38.3°C; condition **CC**: 37.6°C; p=0.002). Although not statistically significant, reductions in core temperature were also seen when cooling was used with normal work dress (condition **WD**: 38.0°C; condition **WC**: 37.7°C; p=0.053). Heart rates were generally above 120 bpm without cooling (conditions **WD** and **CD**) while they generally remained below 120 bpm with cooling (conditions **WC** and **CC**). Limited skin temperature and heat flux information corroborated the core temperature and heart rate data, showing that the Exotemp personal cooling system can alleviate thermal strain in engineering space personnel. Personal cooling is recommended in conjunction with the CD ensemble, and could be considered for routine use with standard dress whenever ships are operating in hot climates.

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INTRODUCTION

In August 1990 the Canadian Government decided to send a naval task force, including five Sea King helicopters, to the Persian Gulf in support of United Nations activities against Iraq. Meteorological data indicated that high ambient temperatures, perhaps as high as 50°C, could be expected in the Gulf. These temperatures, in combination with the wearing of chemical defence (CD) garments, would impose a severe thermal stress on personnel. Aware that thermal stress can affect comfort and performance, and that the consequences of performance degradation in air operations could indeed be severe, the Directorate of Maritime Aviation (DMA) requested the Defence and Civil Institute of Environmental Medicine (DCIEM) to provide personal cooling systems to the deployed aircrew to help reduce the anticipated thermal stress.

A commercially available system, developed and built by Exotemp of Pembroke, Ontario, was identified as a possible approach. A few design changes to the equipment were specified, and Exotemp quickly manufactured sufficient modified units to outfit the deploying aircrew. A brief but highly encouraging laboratory evaluation at DCIEM suggested that the system should be of benefit in reducing thermal strain under the anticipated operating conditions in the Gulf. Integration of the system into the aircraft was completed by DCIEM prior to the aircraft departing from CFB Shearwater, and reports from the Gulf indicated that, unlike their allies, Canadian airmen were not operationally restricted by heat stress.

The unprecedented success of the Exotemp system in the Sea King operations attracted the attention of Directorate of Research and Development Maritime (DRDM) staff who were concerned with heat stress in the engineering spaces aboard the three Canadian ships deployed to the Gulf. Since some of these spaces, notably the boiler room, are outside the collective protection zone of the citadel, these engineering watch-keeping personnel must wear CD garments during times of chemical threat. Even in the engineering spaces within the citadel, air ventilation may be cut off to reduce the influx of fresh air that would have to be filtered free of chemical agents. Again, the combination of high outside ambient temperatures, heat from the boilers and engines, and the wearing of CD garments would result in severe thermal stress. DCIEM was therefore tasked by DRDM to investigate the feasibility of using the Exotemp system to provide personal cooling to engineering space personnel.

Although consideration was given to having a DCIEM team undertake a study aboard HMCS Terra Nova in the Persian Gulf in early January 1991, the complexity, logistics, costs, and risks ruled against the idea. Instead, a physiological and integration trial took place aboard HMCS Ottawa while en route from Halifax to Puerto Rico during the period 22 - 26 January 1991. Although the Ottawa is a different class of ship than the Terra Nova, the engineering spaces are essentially the same and the thermal stress-study results from one ship would be applicable to the other.

The aims of this report are: 1) to describe the Exotemp personal cooling system and outline its integration into the CD garments; 2) to provide results of the physiological evaluations aboard HMCS Ottawa; and 3) to make recommendations to adapt and/or improve the personal cooling system for naval applications in future operations.

I. PERSONAL COOLING SYSTEM DESCRIPTION AND INTEGRATION

The Exotemp personal cooling system was originally developed at Atomic Energy of Canada Limited (AECL) to assist with body heat removal in personnel wearing hazardous materials handling suits. Exotemp was very cooperative in modifying the system on short notice to better meet the requirements of installation and integration into the Sea King helicopter. Based on DCIEM's design recommendations, a new model of fluid reservoir and pump, designated the CD2, was developed and purchased for the present trial. However, the cooling garments were not changed from the earlier design. Procurement details of the system are available in Annex A of this report. The complete system is also described in detail in the Canadian Forces Technical Order CFTO C-22-533-000/MF-000.

Cooling Garmentry

The Exotemp cooling garments consist of a long-sleeved turtle neck undershirt for cooling the torso and arms, long-legged pants (longjohns) for leg cooling, and an open faced hood for head cooling. Previous studies had indicated that head cooling in addition to torso cooling was not essential in some situations (1), and since it would have complicated integration with the CD garments, head cooling was not evaluated in this trial. In fact, only the long-sleeved shirt had been issued to Sea King aircrew, again to minimize integration problems, and it proved to be quite satisfactory in actual operations. It was felt after discussion with naval engineering personnel, however, that both the workloads and the environmental temperatures of the engineering spaces of the ships would be higher than those encountered by aircrew. The present trial therefore included both the long-sleeved shirt and the long-legged pants.

The shirt (Figure 1) and pants (Figure 2) are made of flame retardant Nomex fabric onto which plasticized PVC tubing (1/8" o.d.) has been sewn on the inner surface in parallel serpentine "loops". Note that in this context a single cooling loop consists of a length of tubing running up and down the garment several times. The eight parallel tubing loops of the undershirt cover the entire torso and also extend down the sleeves. They connect to nearly circular fluid distribution and collection manifolds at the neck. The longjohns have two parallel tubing loops in each leg and are connected to the undershirt via small tubing connectors. The cooling cap, if used, can be connected to the undershirt at the neck. The entire cooling undergarment is then connected to the cooling fluid supply via a single pair of feed and return tubes (1/4" o.d.) exiting the undershirt at the waist on the left side.

Although the shirts and pants are available in three sizes, experience with the Sea King aircrew indicated that medium and large sizes should accommodate all personnel. The shirts and pants may be hand or machine washed (warm water, gentle cycle) but must be hung to drip dry.

CD2 Chilled Liquid Source

Cooling fluid is supplied to the clothing from a portable unit consisting of a 2 L plastic bottle fluid reservoir, a variable speed pump, and a battery. These components are all contained in a pocketed insulated nylon pouch (Figure 3). The CD2 assembly differs electrically from that used in the Sea King in that the pump is powered by a 9.6 V rechargeable battery pack (the Sea King units used 28 V pumps that ran on aircraft power). A fully charged pack will power the pump for about two hours, and can be recharged in about one hour. For this trial, extra batteries were purchased so that charged packs were always available as needed.

The water bottle of the CD2 assembly has been redesigned to have the

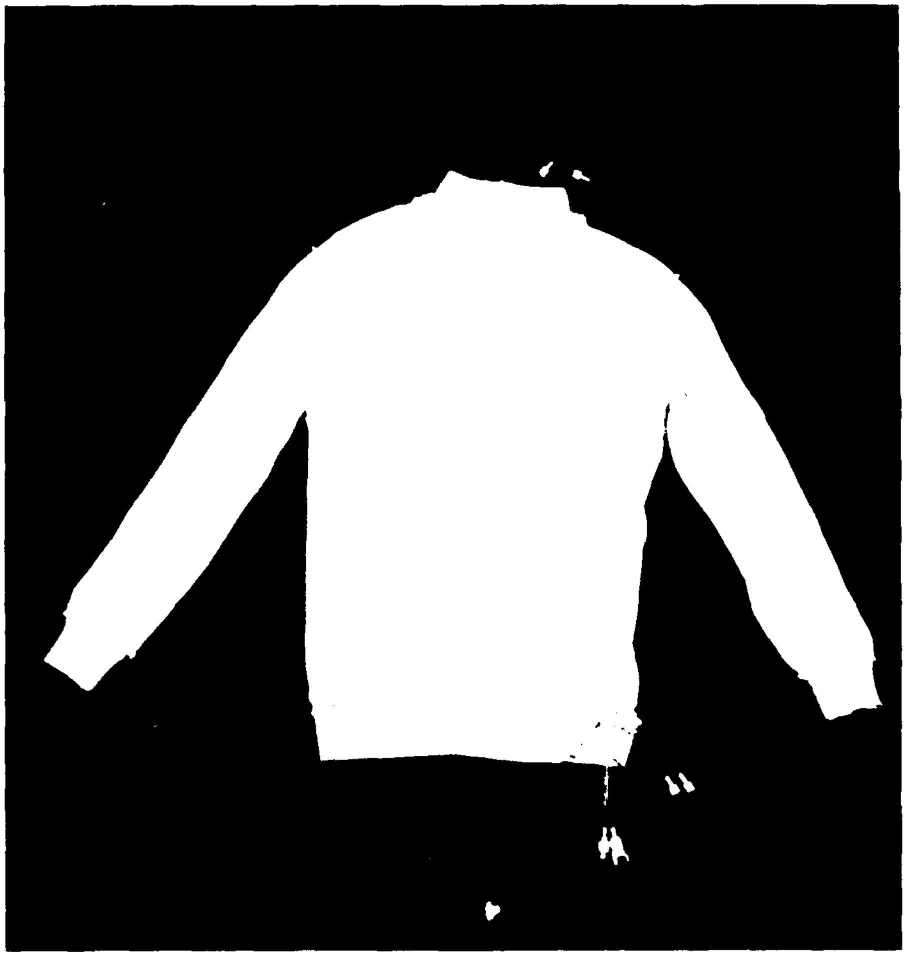


Figure 1.

The cooling shirt of the Exotemp personal cooling system (shown inside-out). The shirt has the main cooling inlet and outlet tubes. It also has tubing connectors with check valves for interfacing with the cooling cap and cooling pants.

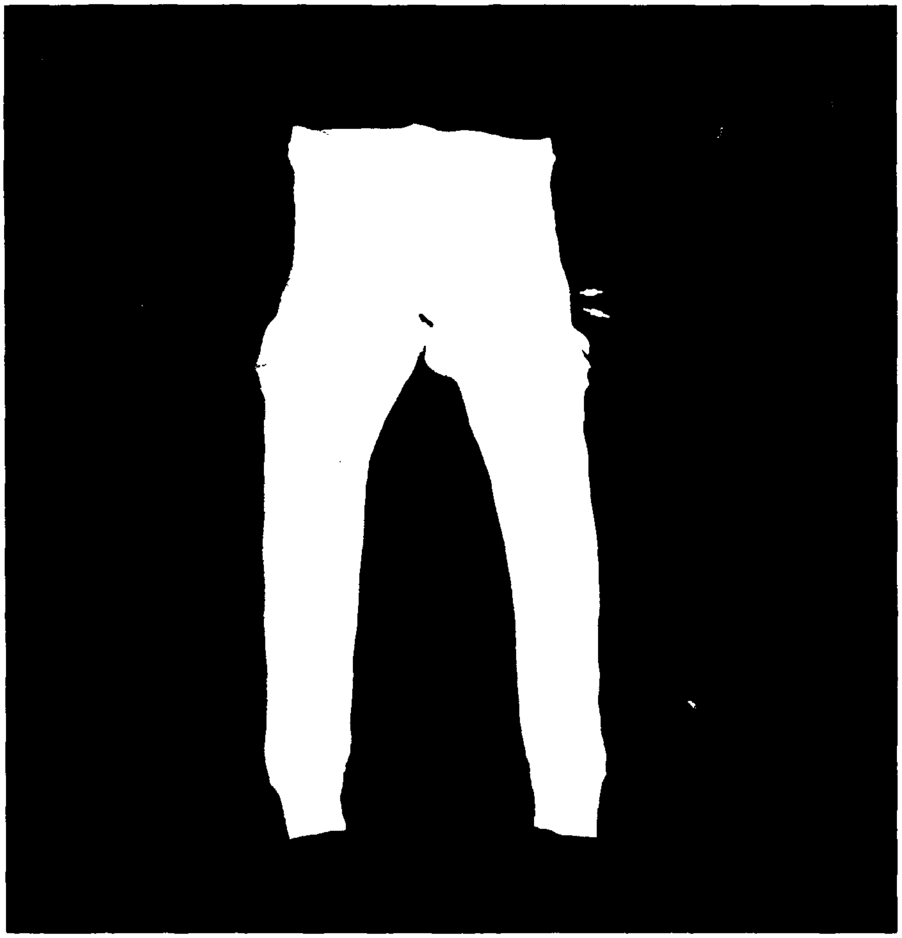


Figure 2.

The cooling pants of the Exotemp personal cooling system. The pants connect to the shirt via tubing connectors. The connectors on the pants do not have check valves, so a small length of tubing with matching connectors sewn to the pants is used to seal off the cooling lines when not connected to the shirt.

Figure 3.

The CD2 assembly. The 2 L bottle fits into the large centre pocket, while the pump and rechargeable battery pack are in pockets on opposite sides of the bottle pocket. The two adjustable straps can be attached in a variety of ways to permit carrying the system on the back, chest, or waist.

cooling fluid entry and exit ports in the cap. This modification permits the bottles to be pre-frozen in an upright position without blockage of the ports (previous designs had the ports on the top and side of the bottle, requiring it to be frozen on an angle). Just prior to use, the bottles are topped up with water. Short lengths of tubing attached to the cap simply project into the bottle below the water line, and body movement provides enough mixing of the ice block and water to ensure sufficient cold water availability.

Finally, the carrying pouch has been redesigned for better comfort and more options with respect to carrying position on the body. Flexibility in wearing is achieved via two adjustable straps with several attachment points, allowing the pouch to be worn on the waist, back, or chest. In the present trial the chest turned out to be the most convenient site. The relocation of the battery and pump pockets to opposite sides of the bottle pocket allows the entire assembly to more or less follow body contours, resulting in greater wearing comfort.

For this trial, cooling bottles were filled with approximately 1.8 L of water and placed upright in a freezer overnight to create a solid block of ice. When required for cooling, the bottles were topped up with water and the standard cap was replaced with the tubing connector cap. Experience during the Sea King trials had shown that the ice bottles provided about 45 minutes of active cooling when used in this manner, whereas they only provided 20-30 minutes of cooling if packed with ice chunks. Extra bottles were ordered so that a ready supply of pre-frozen ice was always available. These spare bottles were kept in a plastic picnic cooler in the engine room and were used to replace spent bottles as the need arose. It should be noted that pump burnout can occur if operated dry or with a fluid obstruction, so the pump should always be switched off during a bottle change.

Integration with the CD Garments

The cooling shirts were designed with the main fluid delivery and return tubes exiting at the bottom left side of the shirt at about groin height. Since this location had also been selected for the Sea King cooling system, similar suit modifications as before are usable to integrate the cooling system into the CD garments. A proper integration would require the installation of two short lengths of tubing into the side of the CD suit so that the cooling garments can be connected to the chilled fluid supply through these tubes without contaminating the inside of the CD suit. A draft Modification Leaflet outlining the suit changes that would be required for integration is included as Annex B to this report.

The modifications developed by DCIEM for integration of the cooling system into the CD suit were not fully implemented for this study due to time constraints. Instead, the left side seams on the CD coveralls were simply opened approximately 3" to permit the tubing from the shirt to pass through and connect directly to the pump umbilical.

Using the same type of connectors on the main garment supply lines, the CD pass-through, and the umbilical to the cooling supply allows the personal cooling system to easily be used either with or without the CD suit. Further, maintaining a common polarity of connectors on all tubing lines from the garments toward the fluid supply greatly simplifies dressing as there is no requirement to find matching male/female connectors. In other words, there is no need to distinguish between fluid supply and return lines. Note that Exotemp supplied the garments with male and female connectors on the shirt, thereby defining inlet and outlet lines, so these changes had to be made locally.

Several types of fluid connectors, with and without check valves, are used in the Exotemp system. Check valves are used on the main fluid supply lines of the shirt to avoid water spillage upon disconnect from the CD suit pass-through. Check valves (of a different type) are also used on the shirt side of the interfaces with the longjohns and cooling cap so that there is no fluid loss from the shirt when it is used alone. The mating connectors on the longjohns and cap do not have check valves, so some dripping can be expected upon separation of these cooling garment components from the shirt. These connections should not be opened in locations or situations where dripping poses a hazard. The longjohns do have a short length of tubing on them to which the pant fluid lines can be connected when not attached to the shirt.

The connectors are friction fit inside the tubing. While tight enough to prevent leakage and inadvertent disconnect during normal use, it is recommended that the connectors be glued into the tubing to prevent their loss during laundering. Even after gluing, the connectors and tubing can still be pulled apart easily enough with force if an individual has to exit an area during an emergency, leaving the pump unit behind.

No physical integration between the portable cooling system and the ship is required, although space is needed for freezing the ice bottles. Using 24 hours as the time required to freeze a bottle of water, and 30 minutes as a conservative estimate of the cooling capacity from a single ice bottle, 48 bottles would be required per 24 man-hours of continuous cooling. If all five men of the watch were to have cooling, 240 bottles of ice would be required each day. The volume occupied by each bottle (including the height needed for the neck and cap) is about 3 L, therefore a freezer space of 720 L (25.2 cu. ft) is required. A location must also be made available for the battery chargers.

II. PHYSIOLOGICAL EVALUATION

Materials and Methods

Test Subjects:

Twelve engine room personnel participated in this trial. This included all four men from the engine room duty posts from each of the three watches. The men were briefed on the experimental procedures and were free to terminate their participation in the study at any time for any reason (i.e., they could leave the engine room, remove the CD and/or liquid cooling suit, and return to duty in normal work dress when they again felt capable of doing so). In this sense, their participation in the study was voluntary.

Scheduling:

The three duty watches (Red, White, and Blue) were scheduled to rotate as per normal ship routine such that five consecutive 4-hour watch periods (First, Mids, Morn, Forn, Aftr; beginning 2000 h) were followed by two 2-hour watches (Fdog, Ldog; beginning 1600 h) in each 24-hour period. This schedule ensures that personnel are on active duty at different times of the day on consecutive days. The latter three 4-hour watches (Morn, Forn, Aftr; 0400 - 1600 h) were selected as the experimental periods during which the study would be conducted. The study was planned to run over three consecutive days such that each group of four men would be monitored once during each of the three watch periods to help randomize circadian effects on body temperature responses.

Since the objective of the study was to measure thermal strain under relatively warm atmospheric environmental conditions, data collection did not commence until outside air temperatures had increased substantially over the -17°C experienced in Halifax on the day of departure (Tuesday, 22 Jan). After one and one half days at sea, air temperatures had increased sufficiently and the study began with the Morn watch at 0400 h on Thursday, 24 Jan. However, because of calm seas and good speed, port in San Juan was reached by mid morning on Saturday, 26 Jan, and two of the data collection periods planned for in the protocol were lost. Thus, only seven of the scheduled nine 4-hour experimental periods were completed.

Clothing Conditions:

Four clothing ensembles were tested in this study. The first, normal work dress (condition **WD**) was examined to provide a baseline of the thermal strain to be expected due to normal work activity in a hot environment in the absence of CD clothing. The second, normal work dress with cooling (condition **WC**), was included to see if personal cooling would be necessary and/or viable for everyday use under hot ambient conditions. The third ensemble examined was the CD clothing without cooling (condition **CD**), and the final ensemble was the CD clothing (complete with C4 respirator and butyl rubber gloves) with the Exotemp liquid cooling system (condition **CC**).

An attempt was made to permute clothing configurations, watch duty, and time of day over the three days of the study. However, given that there were four clothing conditions to be tested but only three test runs per individual, a complete factorial design was precluded. It was decided that each test subject would miss one clothing condition, but even this design was preempted by the early arrival in port. As a result, eight of the 12 subjects only experienced two of the clothing conditions.

Procedures:

Subjects arrived at the Helo EMR room on the main deck approximately 30 min prior to their duty reporting time. They were instrumented for physiological monitoring (see below) and then dressed in the appropriate test clothing as per the desired test schedule. Subjects wearing the CD ensemble wore their standard work dress under the suit. Subjects wearing a cooling system were dressed in the cooling underwear and the appropriate overgarment (either standard work dress, or their work dress and the CD suit) but did not receive cooling until they reached the engine room where the ice bottles were held ready for use.

Throughout each watch period, personnel went about their normal assigned duties as best they could while wearing the particular clothing ensemble. Subjects were told that if they felt they could no longer perform their duties safely or comfortably they should leave the hot environment and remove the CD ensemble. After allowing sufficient time to recuperate, subjects were free to doff any special clothing and return to their duties for the remainder of the watch period wearing normal work dress.

Environmental Conditions:

At the beginning of each watch, the engine room ventilation fans were turned off to simulate a closed down condition and permit the ambient temperatures to rise. Operators were instructed to keep the fans off as long as possible (i.e., tolerable) without jeopardizing required operations.

Environmental conditions in the engine room were monitored for wet-bulb (Twb), dry-bulb (Tdb) and globe (Tg) temperature using two Reuter-Stokes WIBGET RSS-217 solid-state recording WBGT meters. One recorder was positioned on a shelf just forward and starboard of the main console, and a second meter was hung from the hand rail of a gangway in the aft area of the engine room over the engine flats. Environmental data were logged at 5-min intervals throughout the 12 hours of the three watches. These data were transferred to a Zenith laptop computer for storage and later analyses.

Physiological Monitoring:

All subjects were instrumented for core temperature and heart rate measurements. Deep body temperature was measured with a rectal thermistor inserted 15 cm beyond the anal sphincter. Heart rate was measured with a single lead ECG configuration using three chest electrodes. Both parameters were logged every minute using DCIEM's portable solid-state Data Recorders (SSDRs). These devices can log up to 32 channels of information, storing upwards of 4000 readings per channel in non-volatile solid-state memory. The logged data were also transferred to the Zenith laptop computer upon completion of each test run.

As a backup system, heart rate was also recorded with a Polar Electro Sport Tester PE3000 telemetry system. This system is comprised of an elastic chest strap with 2 conductive rubber pads that connect to a telemetry module to measure heart rate. The information is transmitted to a wristwatch which records the heart rate at prescribed intervals. The wristwatch data were also downloaded to the Zenith laptop for storage and later analyses.

In addition, on two occasions (conditions **C D** and **C C**), one subject was instrumented with a 12-point skin temperature and heat flux measurement harness. These data were also logged on the SSDR. Mean skin temperature and mean body heat flux were calculated as the surface-area-weighted mean of the transducers using a standard weighting system (2).

Data Analyses:

All data recorded during this study were transferred from the Zenith laptop to a Macintosh desktop computer at DCIEM for processing and analyses. The data were analyzed statistically using the StatView II (Abacus Concepts) statistics package for the Macintosh. Unpaired one-tailed t-tests were performed between cooled and uncooled clothing conditions for both the standard work dress and the CD ensemble. Unpaired analyses were used because there were insufficient data for paired analyses due to subjects only wearing three of the four clothing ensembles, the early arrival in port, and to the inadvertent loss of two sets of rectal temperature data.

For these analyses, all data from all subjects wearing a particular clothing ensemble were combined despite the fact that they performed four different jobs in the engine room. This approach is justified by the fact that there were no significant differences between environmental conditions at the two engine room monitoring locations (see below). Further, even those personnel who were required to move about in the engine room only did so for a relatively small portion of their duty time, spending the rest of the time at or near the console with the other watch personnel. Thus, subjects performed relatively similar work under very similar environmental conditions. Perhaps the strongest justification for combining the data in this manner is the fact that this was a field trial with limited scope for a repeated-measures factorial design. Attempts to analyze the data in any other manner (i.e., trying to factor in job or time of day) would be meaningless because of the small sample sizes in the resultant subgroups. The procedures adopted in this study resulted in sample sizes of 7 for the two cooled conditions and 6 for the two uncooled conditions.

Results and Discussion

Environmental Conditions

The globe (Tg) and wet-bulb (Twb) temperatures recorded by the WIBGETs were used to calculate the indoor WBGT Index at each engine room monitoring site according to a standard formula (WBGT=0.3 Tg + 0.7 Twb). Figure 4 presents these results as a function of time of day for each of the three days of the study.

Several features of Fig. 4 should be noted. First, 5 of the 7 watches indicate brief (~90 min) periods of relatively high temperatures followed by longer plateau periods at lower temperatures. The initial periods of high temperature were the result of turning off the engine room ventilation fans at the beginning of each watch. However, conditions became so intolerable, even in work dress, that the fans were turned on again after about 90 minutes. Many subjects wearing the CD ensemble could not work longer than about 90 minutes, so all subsequent physiological data analyses have been confined to the first 90 minutes of each watch period (shaded areas of Fig. 4).

Second, the lower plateau temperatures of each watch while the ventilation fans were operating climb steadily as the days progress. This trend is particularly evident in the WBGT data for Day 2 where a gradual warming over the day is apparent. This was the result of the ship's continuing southward progress into warmer atmospheric conditions. By Day 3, conditions were so warm that WBGT temperatures exceeding 35°C occurred even with the fans running.

Finally, the actual levels of the WBGT Index during the initial 90-min period of each watch were always above 32°C, they exceeded 35°C in 6 watches, and peaked at over 40°C for 5 of the 7 experimental watches. The

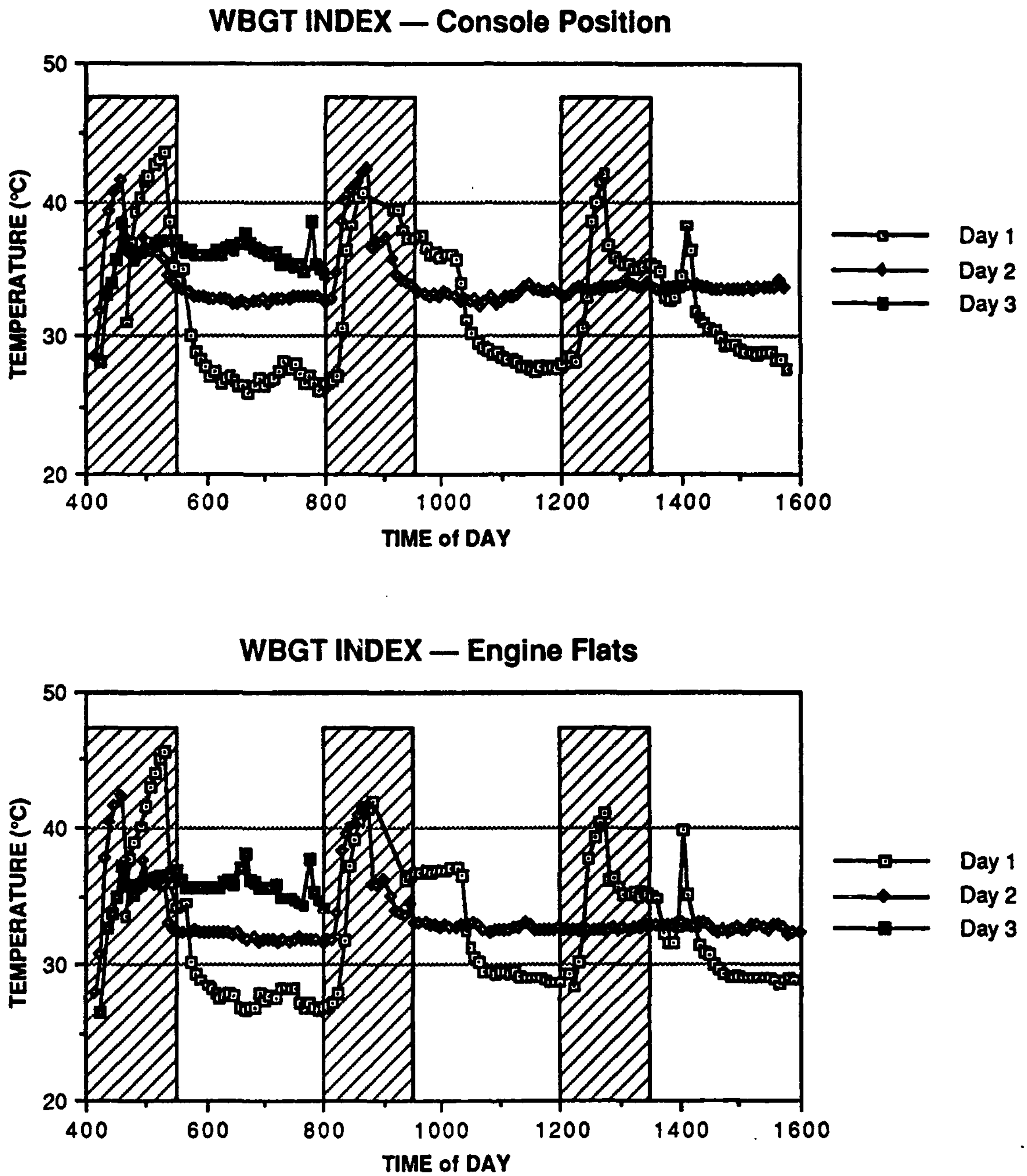


Figure 4.

WBGT Index near the control console and over the engine flats vs time of day for the three days of the study. The peaks in temperature occurred during the shaded periods when the engine room ventilation fans were turned off (about 90 minutes duration at the beginning of each watch). Note that Day 3 data only consists of the early watch from 0400-0800 hours due to early arrival in port.

American Conference of Governmental Industrial Hygienists recommends, and CFAO 34-47 and CFMO 40-02 have adopted, that a WBGT Index of ≥32.2°C is a stressful enough environment such that unacclimatized workers in normal clothing performing normal work duties should follow a work/rest schedule during each hour of duty that includes three times as much rest as work.

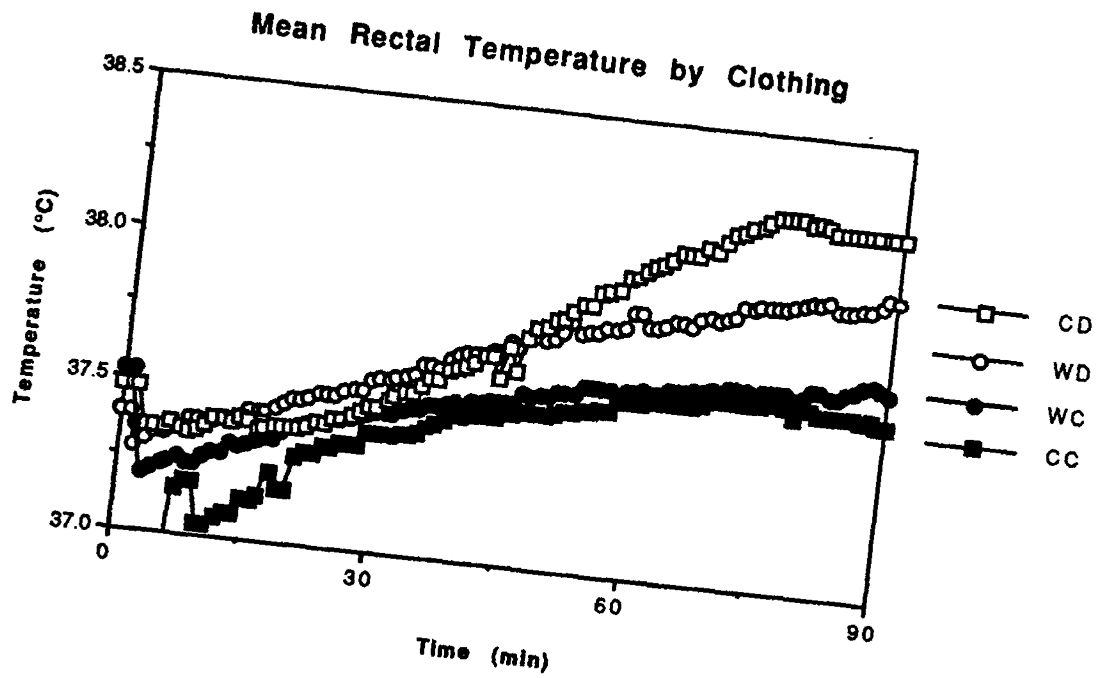
It has also been suggested that a 5°C downward correction be applied to the WBGT Index to allow for the effects of CD clothing (3). The data of Fig. 4 show that the WBGT Index was always above 27.2°C even with the fans operating. Clearly, the engine spaces of a ship can be thermally stressful environments, and supervisors must be on the alert for signs and symptoms of heat illness when CD clothing is worn.

39. For a more detailed look at the engine space environmental conditions, Figures C-1 through C-3 in Annex C contain complete dry-bulb, wet-bulb, and globe temperature data plots from both monitoring locations for each day of the study. As a matter of interest, relative humidities in the engine room were generally below 40% as calculated from the wet-bulb depression.

Rectal Temperatures

Figure 5 presents the mean rectal temperatures (upper panel) and the mean changes (Δ's) in rectal temperature (lower panel) over time for the four clothing conditions tested. The data are averages over all subjects wearing the particular clothing ensembles and therefore include a range of engineering duties. Sporadic losses of data occurred in this trial due to rectal probes occasionally becoming disconnected from the recorders. This alters the number of data values in the means and explains the minor irregularities in the data plots of Fig. 5.

As stated previously, physiological data analyses were restricted to the



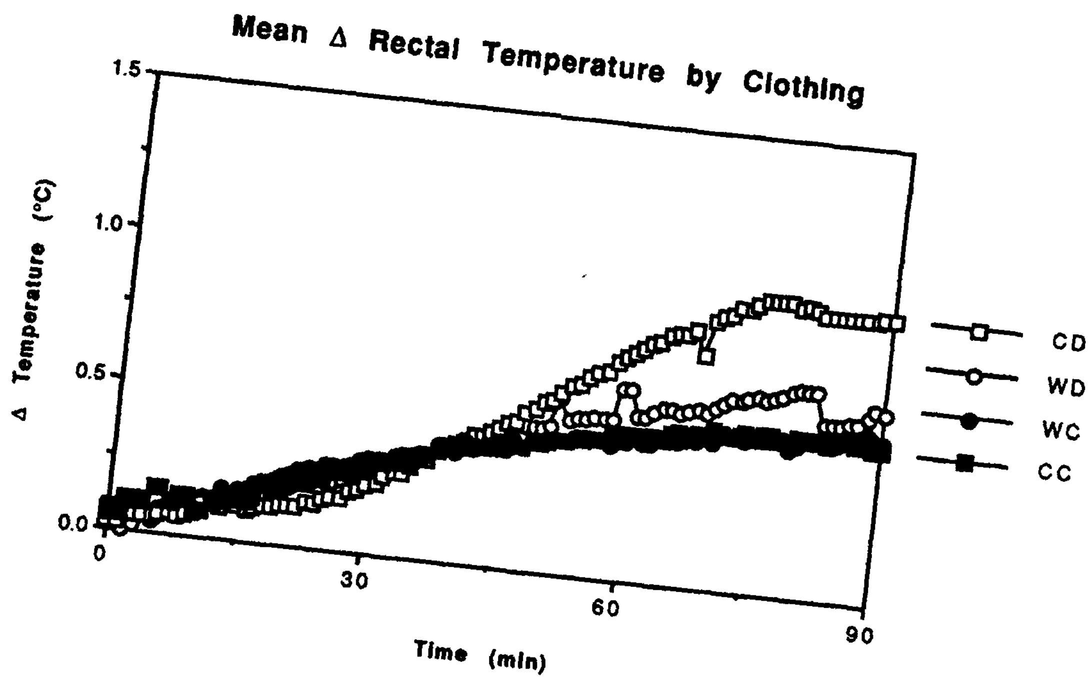


Figure 5.

Mean rectal temperature and mean change in rectal temperature (Δ) vs time for the four clothing conditions. WD: standard work dress; WC: standard work dress with cooling; CD: chemical defence ensemble; CC: chemical defence ensemble with cooling. The data for conditions WC and CC are very similar, especially when looking at changes in rectal temperature.

first 90 minutes of each watch to coincide with the period of time during which the ventilation fans were off. However, due to inadvertent probe disconnects, two rectal temperature data values at 90 minutes were missing. For these cases, 90-min values were interpolated based on subsequent values. Also, two subjects left the engine room at 75 minutes, and one subject exited the area at 65 minutes of exposure, all due to excessive discomfort. Since rectal temperatures were still being recorded in these subjects, the maximum rectal temperatures recorded during the first 90 minutes were used as the 90-min values. Should any of these manipulations of the data seem dubious, unadjusted rectal temperature values at 75 minutes were also analyzed. The complete rectal temperature data at 75 and 90 minutes of elapsed time as subjected to statistical analyses are shown in Table 1 (note that two sets of data were completely lost due to malfunction of an SSDR).

Table 2 presents the results of the statistical analyses of the 75- and 90-min rectal temperature data. At both time points, the Exotemp system significantly ($p<0.05$) affected rectal temperature responses during the wearing of CD clothing. Actual rectal temperatures were significantly lower with cooling, as were the increases in rectal temperature over the time of exposure. In fact, rectal temperature increases were 46% and 48% smaller at 75 and 90 minutes, respectively, when wearing CD clothing with the cooling system compared to CD clothing without cooling. Figures 6 and 7 present the mean rectal temperatures and mean changes in rectal temperature at 75 and 90 minutes, respectively, in graphic form.

It is interesting to note that while the Exotemp cooling system was of some benefit when wearing standard work dress, the benefits were not statistically significant. There are several possible explanations for this. One may be that the additional insulation of the CD garment reduces heat absorption from the environment by the cooling system, thereby making it more efficient at removing heat from the body; hence a more significant cooling

Table 1

Rectal Temperature and Change in Rectal Temperature at 75 and 90 min of Each Duty Watch

Run	Day	Watch	Duty	Subj	Dress	Tre-75	ΔTre-75	Tre-90	ΔTre-90
1	1	1	E	1	WD	37.55	0.40	37.90	0.75
2	1	1	T	2	WC	37.55	0.40	37.95	0.80
3	1	1	I	3	CD	38.60	1.45	38.80	1.65
4	1	1	O	4	CC	37.70	0.20	37.60	0.10
5	1	2	E	5	WD	38.50	0.65	38.50	0.65
6	1	2	T	6	WC	37.65	0.35	37.70	0.40
7	1	2	I	7	CD	38.30	1.40	38.30	1.40
8	1	2	O	8	CC	37.75	0.55	38.00	0.80
9	1	3	E	9	CD	38.10	0.90	38.40	1.20
10	1	3	T	10	CC	37.50	0.50	37.55	0.55
11	1	3	I	11	WD	38.40	1.05	38.50	1.15
12	1	3	O	12	WC	37.85	0.55	37.80	0.50
13	2	1	E	5	CD	38.60	0.90	38.60	0.90
14	2	1	T	6	CC	37.20	0.60	37.20	0.60
15	2	1	I	7	WD	38.00	1.10	38.25	1.35
16	2	1	O	8	WC	37.55	0.55	37.35	0.35
17	2	2	E	9	WD	•	•	•	•
18	2	2	T	10	WC	37.40	0.80	37.40	0.80
19	2	2	I	11	CD	38.20	1.25	38.20	1.25
20	2	2	O	12	CC	37.75	0.60	37.70	0.55
21	2	3	E	1	WC	37.85	0.25	37.85	0.25
22	2	3	T	2	CD	37.55	-0.10	37.60	-0.05
23	2	3	I	3	CC	37.85	0.35	37.85	0.35
24	2	3	O	4	WD	37.55	0.05	37.50	0.00
25	3	1	E	9	WC	37.75	0.65	37.80	0.70
26	3	1	T	10	CD	•	•	•	•
27	3	1	I	11	CC	37.55	0.85	37.60	0.90
28	3	1	O	12	WD	37.60	0.65	37.55	0.60

Duty Codes:
E — EOOW — Engineering Officer of the Watch
T — THROTTLES — Throttles Operator
I — INS RDS — Inside Roundsman
O — OUTS RDS — Outside Roundsman

Dress Codes:
WD — Standard Work Dress
WC — Standard Work Dress with Exo-Temp Cooling
CD — Chemical Defence Ensemble
CC — Chemical Defence Ensemble with Exo-Temp Cooling

Table 2

Summary of Rectal Temperature Statistics

Data	Dress	Mean	S.E.M	n	p
Tre-75	WD	37.93	0.18	6	*0.074*
	WC	37.66	0.06	7	
	CD	38.23	0.16	6	**0.002**
	CC	37.61	0.08	7	
ΔTre-75	WD	0.65	0.16	6	*0.206*
	WC	0.51	0.07	7	
	CD	0.97	0.23	6	**0.040**
	CC	0.52	0.08	7	
Tre-90	WD	38.03	0.18	6	*0.053*
	WC	37.69	0.09	7	
	CD	38.32	0.17	6	**0.002**
	CC	37.64	0.10	7	
ΔTre-90	WD	0.75	0.19	6	*0.161*
	WC	0.54	0.09	7	
	CD	1.06	0.24	6	**0.033**
	CC	0.55	0.10	7	

Notes: Dress codes are as in Table 1.
Statistical analyses comparing cooled and uncooled clothing ensembles were performed with Student's unpaired one-tailed t-test.
Statistical probabilities in Roman bold type are significant at $p<0.05$.

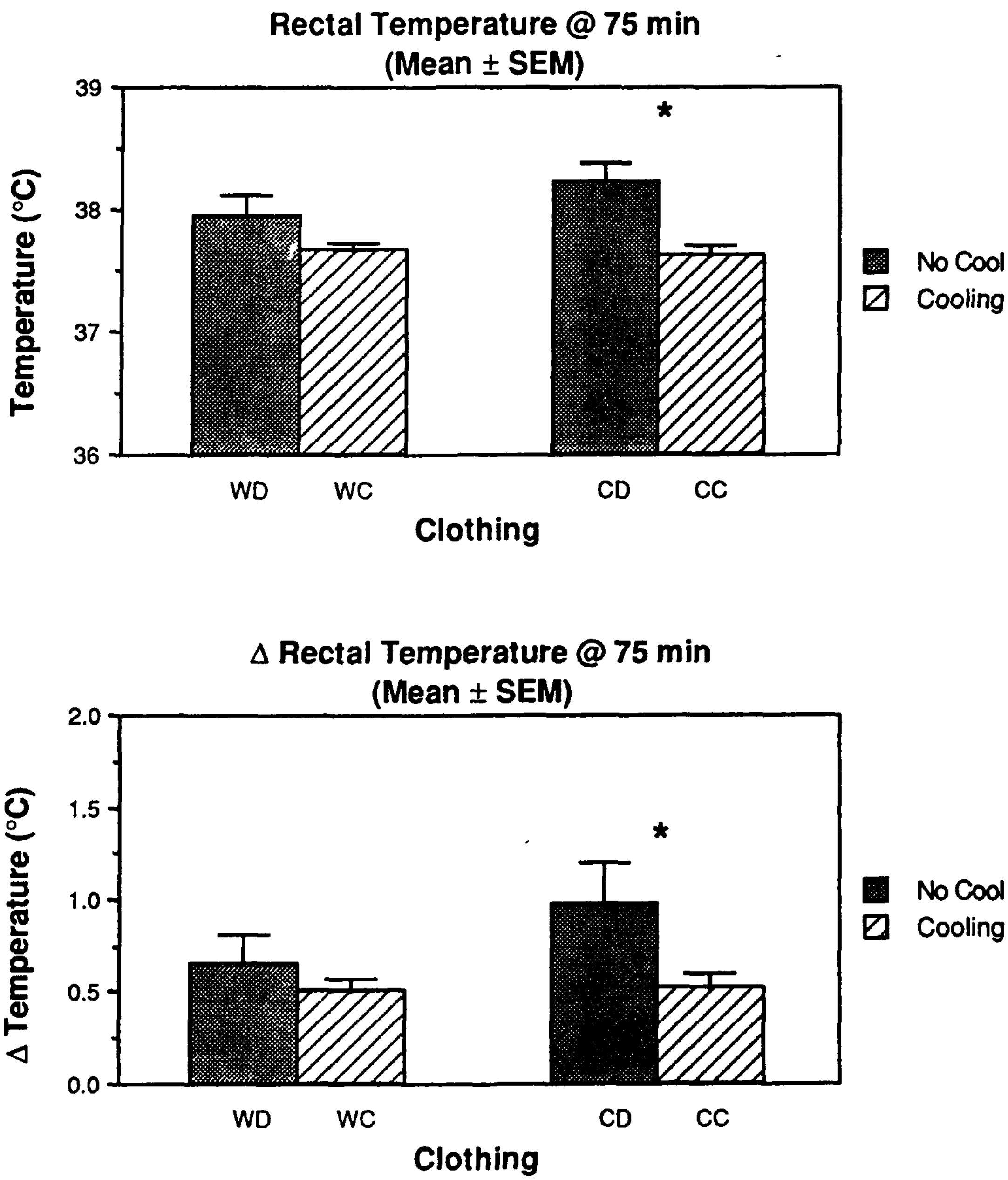


Figure 6.

Rectal temperature and change (Δ) in rectal temperature at 75 minutes for the four clothing conditions examined in this study. Data are means over all subjects wearing the particular ensemble. The asterisk indicates a statistically significant difference at $p<0.05$ between cooling and no cooling with the CD ensemble.

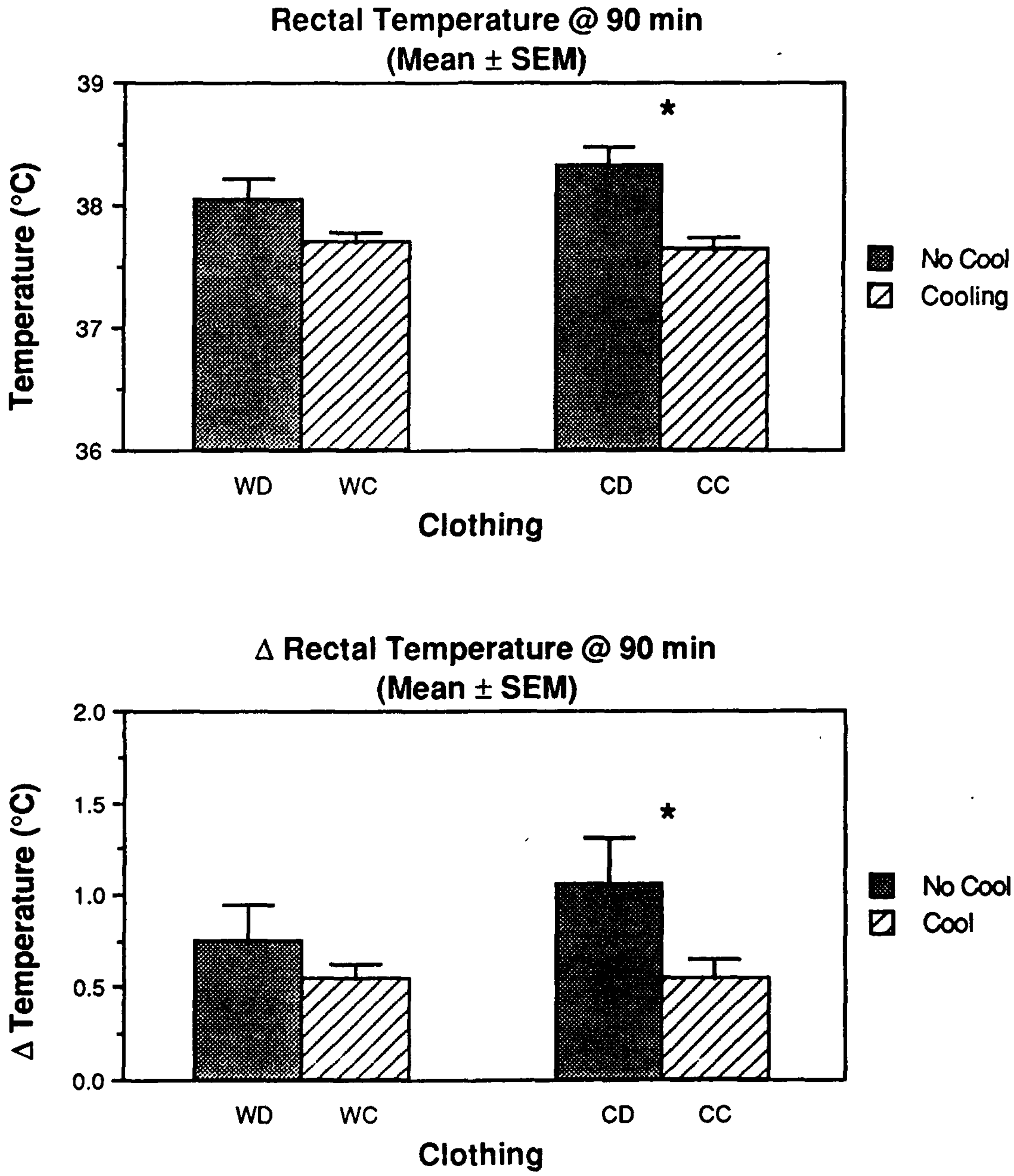


Figure 7.

Rectal temperature and change (Δ) in rectal temperature at 90 minutes for the four clothing conditions examined in this study. Data are means over all subjects wearing the particular ensemble. The asterisk indicates a statistically significant difference at $p<0.05$ between cooling and no cooling with the CD ensemble.

effect. We have laboratory data (unpublished) that show liquid-based cooling garment efficiency improves as the insulation of the overlying garments increases. However, further tests with the Exotemp system under various conditions would be required to quantify the dependence of this cooling garment's efficiency on the overlying insulation and to determine the contribution of this effect to the observed results.

An alternative explanation is reached by noting that the statistically significant effect of the cooling system with the CD garment is primarily due to the greater thermal strain that occurred when the CD garment was worn without cooling. In fact, the values of actual or change in rectal temperature with cooling, at either 75 or 90 minutes, were virtually identical irrespective of which outer garment was worn (compare conditions **WC** and **CC** in Table 2 and in Figures 6 and 7). This suggests that the Exotemp system created a microenvironment around the body that effectively isolated it from thermal influences beyond the cooling garment. Under such circumstances, body temperature would be regulated primarily according to metabolic heat production (dependent upon the physical work being performed) and the heat loss to the garment (dependent upon the temperature and flow rate of the cooling fluid in the garment). Assuming that the physical work being performed was essentially the same under all conditions, and that the cooling system performed consistently at all times, one would expect very similar levels of thermal strain whenever the cooling system was used. This hypothesis appears to be well supported by the data.

Whatever the explanation for the results, the selection of a statistically significant threshold, such as $p<0.05$, is somewhat arbitrary, and the p-values of several of the **WD** to **WC** comparisons in Table 2 are very nearly statistically significant. Furthermore, the p-values do become smaller as a function of time. This, not surprisingly, suggests that there is an increasing benefit of the cooling suit with duration of exposure. The reductions in thermal strain and improvements in thermal comfort afforded by the Exotemp system when used in conjunction with standard work dress should, therefore, not be overlooked, and a personal cooling system may be a beneficial addition to the standard work dress for engineering space personnel.

As far as the actual levels of thermal strain are concerned, core temperatures in this study did not reach particularly high or dangerous levels. A core temperature of 39°C is a widely used limit for experimental exposures in the laboratory because it is very near the physiological tolerance limit for voluntary exposure to heat. None of the subjects in this study reached this limit for core temperature, although one subject wearing CD clothing without cooling came close (Run 3 in Table 1). The heat exposures in this study were more likely terminated because of excessive discomfort, and they ended either when subjects left the engine room or when the fans were turned on again.

From an operational performance perspective, there is controversy over just what constitutes a disabling core temperature. Some researchers claim significant performance decrements occur with core temperature increases as small as 0.6°C (4,5), while others believe performance is virtually unaffected right up to the physiological tolerance limit (6,7). The discrepancy in the literature is likely due to a complex interaction of factors that ultimately affect performance, and to variations in experimental conditions among the various tests (i.e., different criteria of performance such as muscular endurance, vigilance, cognitive reasoning, etc.; different levels of distraction, motivation, etc.; different experimental protocols with variations in activities, timings, etc.). In the present study, personnel were still able to function, but environmental stress, workload, and clothing effects probably combined to produce enough thermal strain and discomfort in the test subjects to cause them to withdraw from the study.

Heart Rates:

Figure 8 shows the mean heart rate data recorded during the first 90 minutes of the watch periods for the four clothing configurations. The upper panel compares conditions **WD** and **WC**, while the lower panel compares conditions **CD** and **CC**. Again, the data at each time point are averaged over all subjects wearing the specific clothing ensembles, and the number of data values in each point varied slightly due to sporadic data losses and/or subject dropouts.

In both panels it is evident that the addition of a cooling garment has a clear effect of reducing heart rate. Whereas without cooling heart rates were generally in the 120 - 160 bpm range, the Exotemp cooling system kept heart rates typically below 110 bpm. From strictly an exercise work rate perspective, 120 bpm is a very crude break point between light and moderate work rates for healthy young individuals as used in this study. In this case physical work was primarily very light, therefore the observed heart rates were most likely due to thermal stress on the body. Nevertheless, the observed separations in heart rates around 120 bpm can be interpreted as bridging an important threshold with respect to stress on the body.

It is interesting to note that during condition **WD** heart rates rose fairly steadily throughout the test period while during condition **CD** heart rates rose rapidly early in the test period and then remained high throughout. This probably reflects the greater thermal stress experienced when wearing the CD ensemble. It is also interesting that the heart rates for both cooled conditions were similar. This is in agreement with the change in rectal temperature data seen in the lower panel of Figure 5, where conditions **WC** and **CC** are also virtually indistinguishable.

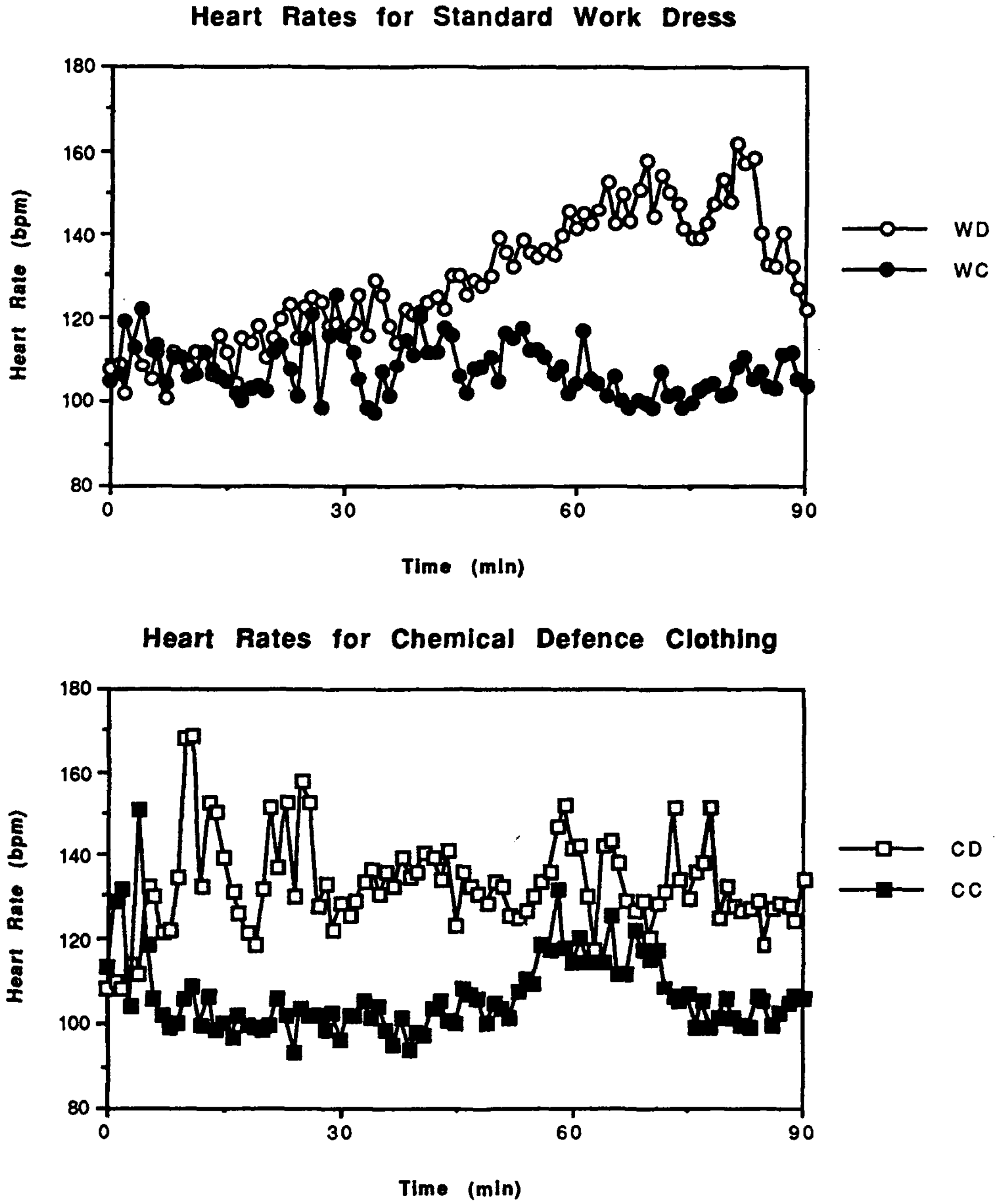


Figure 8.

Heart rate vs time for the four clothing conditions. The data have been separated to facilitate comparison of cooled and uncooled conditions for standard (upper panel) and chemical defence (lower panel) clothing. WD: standard work dress; WC: standard work dress with cooling; CD: chemical defence ensemble; CC: chemical defence ensemble with cooling.

Skin Temperatures and Heat Flux:

As mentioned previously, one subject on two occasions (conditions **C D** and **C C**) was instrumented with 12 transducers to measure mean skin temperature and mean heat flux. Figure 9 presents these results as a function of time. Although a full 90 minutes of data are presented, it should be noted that this subject left the engine spaces at about the 75-min mark during condition **C D** due to excessive discomfort and malaise.

In the upper panel it is clear that skin temperature rose progressively throughout the test period in the absence of body cooling (open squares) up until the time of exit from the engine room. A normal comfortable resting mean skin temperature is about 33°C, and in this case the skin temperature rose to levels of deep body or core temperature by about the 60-min mark. When skin temperature is that close to core temperature, it indicates significant thermal stress as there is no longer a gradient from core to skin through which metabolic heat can be dissipated (8). Under these conditions, the body is maximally vasodilated and the hot blood from the core is being sent right to the surface in an effort to maximize cooling of that blood.

In contrast, the use of the Exotemp cooling system maintained skin temperatures at much more comfortable levels throughout the exposure (upper panel, solid squares). The effect of initially providing the ice water supply bottle at about 30 minutes, and of replacing it at about 60 minutes, is evident in the skin temperature record.

The lower panel of Figure 9 presents the mean whole body heat flux as calculated from the 12 heat flux transducers. Looking first at the open squares for condition **C D**, body heat loss dropped quickly upon entering the engine room from a normal 50 $W \cdot m^{-2}$ to extremely low values until the subject's exit at about 75 minutes. In fact, whole body heat exchange was often negative,

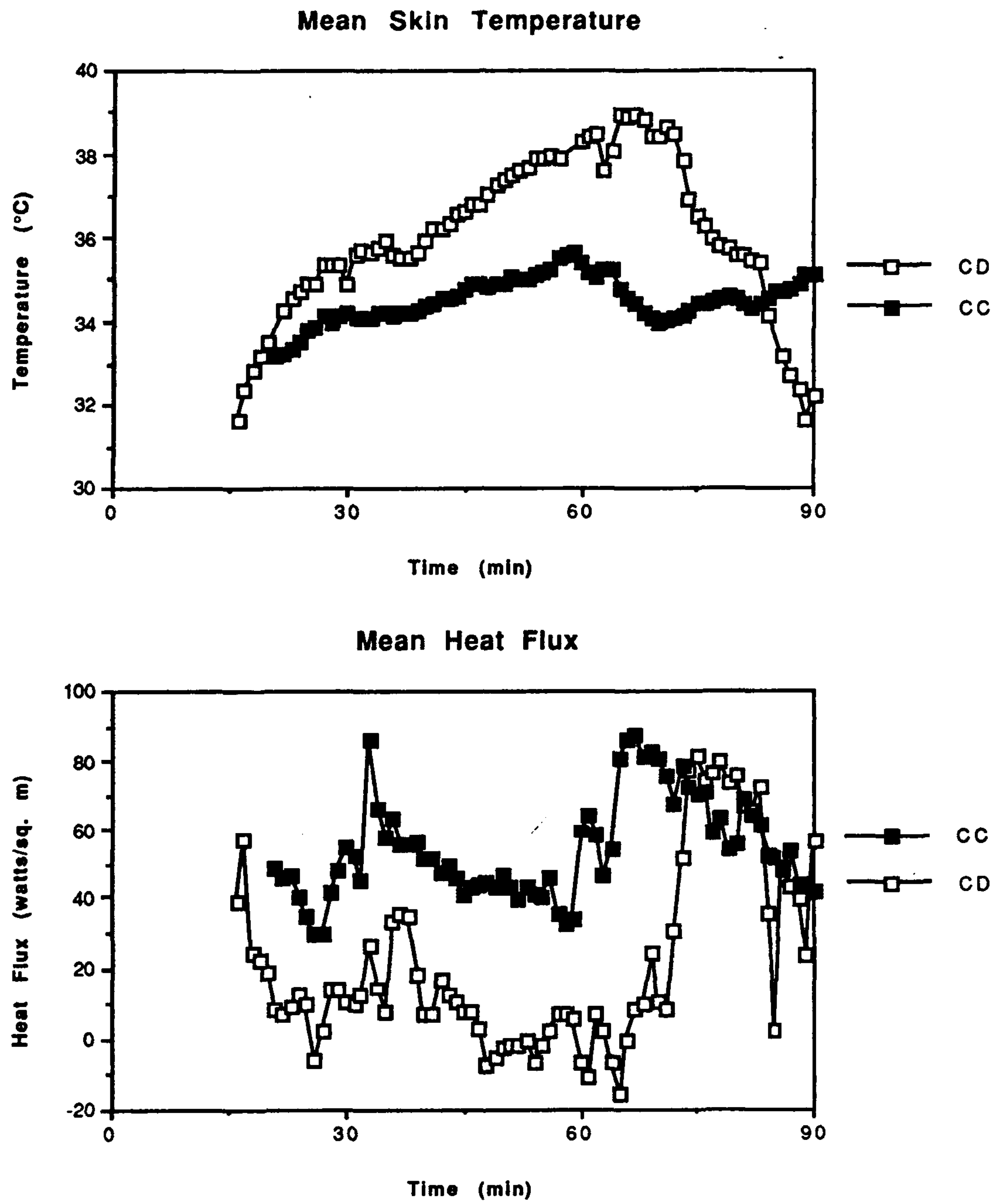


Figure 9.

Mean skin temperature (upper panel) and mean heat flux (lower panel) vs time. The data are from one subject only while wearing chemical defence (CD) clothing or chemical defence clothing with cooling (CC).

indicating a net heat gain from the environment. Upon exit from this hot environment, the subject opened the CD garment, thereby substantially increasing the heat transfer between his hot body and the somewhat cool environment of the air conditioned mess.

The solid squares in the lower panel show the whole body heat flux during condition **C C**. In general, heat removal from the body was considerably higher with the active cooling system. The effects of initial provision and the subsequent replenishment of the ice water (i.e., the large increases in heat loss near 30 and 60 minutes) are even more evident in this data than in the skin temperature results. This is attributable to the high sensitivity and rapid response of the heat flux transducers used in this study. Although not shown here, the cyclic pattern of heat flux was very prominent with each of the five bottle changes over the 240 minutes that the subject wore the CD garment with cooling.

As mentioned above, normal heat dissipation for a man with almost 2 square metres of body surface area is about 50 $W \cdot m^{-2}$ under resting conditions. This takes care of the approximately 100 W of heat being produced during rest at normal ambient temperatures while wearing normal clothing. In this study, metabolic rates were not measured, but clearly there was a greater heat production in the body due to the work being done. In addition, the high ambient temperatures of the engine space were a heat load on the body, rather than a heat sink, and the wearing of the CD garments made the dissipation of heat that much more difficult. This means that a "normal" heat removal of 50 $W \cdot m^{-2}$ is not adequate to completely prevent thermal strain under these conditions. However, considering that in the absence of cooling there was a definite heat gain from the environment (open squares are negative from 45-65 min), the provision of 40-80 $W \cdot m^{-2}$ of body cooling with the Exotemp system is at least a positive step to reducing thermal strain. This conclusion is consistent with the remainder of the data which indicated not an elimination but rather a diminution of thermal strain with the cooling system.

Summary and Conclusions

The data collected in this study constitute relatively good field data. Although the environmental conditions could not be as tightly controlled as they can be in a laboratory setting, the first 90 minutes of each watch period did provide thermal stress conditions comparable to what was desired. The subjects were very cooperative and tolerant of the experimental procedures, and a reasonably comprehensive set of physiological data was collected.

The data show that the engineering spaces of ships such as the HMCS Ottawa do get extremely hot when operating in warm climates with the ventilation fans turned off. Under these simulated CD conditions the environment rapidly becomes intolerable even in standard work dress, let alone in CD clothing. Considering that engine room personnel terminated their voluntary exposure to the excessive heat by turning on the fans after about 90 minutes, one can conclude that the maximum safe operating time of the ship with engine room ventilation off is considerably less than the four hour duration of a normal watch period. Longer operating times could be achieved by more frequent shift rotations, or by active body cooling.

The rectal temperature, heart rate, skin temperature and heat flux data all show that the Exotemp personal cooling system is capable of reducing thermal strain in engine room personnel exposed to severe heat stress. Although the entire Exotemp system including the CD2 unit was evaluated, the physiological results pertain mainly to the performance of the cooling garments. The data indicate that the garments will provide significant reductions in thermal strain and will allow personnel to function longer and in greater comfort, particularly when wearing the CD ensemble, as long as a supply of cold fluid is available.

III. RECOMMENDATIONS

The WBGT data from this study show that the engineering spaces aboard Canadian Forces vessels operating in hot climates can indeed be very stressful environments. There is little doubt from the results that when the ventilation fans are off the conditions are intolerable when personnel are wearing CD clothing. Under these circumstances, personnel must either be rotated frequently, or some means of actively reducing thermal strain, such as wearing a personal cooling system, must be adopted.

The data also show that the environmental stress, even with the ventilation fans on, can exceed the WBGT guidelines recommended in CFAO 34-47 and CFMO 40-02 for normal work conditions. This suggests that a personal cooling system might be a useful adjunct even to standard work dress whenever ships are operating in hot climates.

The present study showed a statistically significant reduction in thermal strain in shipboard engineering space personnel wearing the Exotemp personal cooling system in conjunction with CD clothing. The cooling system also reduced thermal strain in personnel wearing standard work dress, although these reductions did not reach statistical significance during the period of exposure. From an operational perspective, the study showed that the system as configured with a portable cooling pack strapped to the chest can be integrated successfully into engineering space duties, and no hardware modifications to the ship are required.

Much effort has gone into the development of personal cooling systems for military applications over the past several decades. While many systems appear to perform well in laboratory and experimental field trials, the only military personal cooling system known to the authors to have been made operational (excluding our own Sea King system) is an air cooling system on the American M1E1 tank (9). A major factor preventing the successful implementation of personal cooling systems, particularly for aircrew, has been the hardware that supplies the cooling to the garment. Most systems are simply too big, too heavy, too power hungry, or too impractical from a logistics perspective to permit them to be added to existing military vehicles.

Such hardware constraints may be less stringent in the case of ships. Certainly, weight and power should not be a problem, leaving space as perhaps the major limitation. The Exotemp system evaluated in this study does not interface directly in any way with the ship, although about 720 L of freezer space are required to accommodate the bottles. If this amount of space is available, then the system as tested in this study can easily be incorporated.

The most cumbersome aspect of the Exotemp system is the logistics of supplying adequate quantities of ice to provide continuous cooling over a 24 hour period. The data of this study, together with our laboratory evaluations of the Exotemp system, indicate that the cooling garments themselves are quite effective in removing body heat, provided there is an adequate supply of cooling fluid. This opens the possibility of providing cooling fluid from some other source.

For example, Exotemp provides a two-person cooling assembly that can be connected to two men via umbilical tubes. While this system may relieve the individual person of the burden of carrying a portable cooling pack, it does not eliminate the problem of ice supply, since the multi-person unit is essentially a cooler that holds ice in bulk.

Considering the duties and tasks of engineering space personnel, it is possible that much of the personal cooling requirement can be met by having fixed cooling stations located near the console. Watch personnel could then simply plug in a cooling umbilical to one of these fixed stations and receive cooling fluid continuously. The length of the umbilical would, of course, have to be optimized to provide adequate mobility without undue encumbrance or entanglement. Personnel who must make rounds in the engineering spaces could then disconnect from the fixed station and either carry out their duties without cooling, or they could pick up a portable pack for the short duration of their rounds.

The cooling fluid at the fixed stations could be supplied from a variety of sources running on ship power directly. Sources could include an existing cold water line routed into the area, a commercially available fluid chiller running on electric power (perhaps a modified drinking water cooler), or a refrigeration system custom designed for this application. Any of these approaches would reduce the requirement for ice and the need to service portable cooling units on a regular and frequent basis.

In summary, DCIEM would support a recommendation to pursue the installation of the Exotemp personal cooling system on board CF vessels. Active body cooling is essential if personnel are to be functional as per normal ship routine while wearing CD garments and operating in hot climates. Personal cooling would probably be useful even in standard work dress when operating in hot climates. However, the service life of the components is not known at the present time, and the extended costs of running such equipment on a daily basis would have to be evaluated.

ACKNOWLEDGEMENTS

The authors wish to thank all of the crew of the HMCS Ottawa for their excellent cooperation and support of this trial. Special thanks are extended to: Cdr Perusse for permitting the trial to be conducted aboard his ship; to the Executive Officer LCdr Bell and the Chief Engineering Officer Lt(N) Proulx for arranging test space and test personnel; and to the ship's supply officer Lt(N) Hebert and his staff for supplying the CD clothing and equipment, as well as freezer space. A very special thanks to the twelve "brave" men who volunteered to be the test subjects in this study, without whom the trial could not have proceeded. The able technical assistance of Sgt. Belzile and Mr. Robert Limmer, which in the face of severe motion sickness often approached heroic proportions, was very much appreciated.

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ANNEX A

PERSONAL COOLING SYSTEM
PROCUREMENT DETAILS

ITEM	P/N	COST (6 Dec 90)
Pro-Kool Nomex Hood	1087	$39.56
Pro-Kool Nomex Pants, High Performance		
Size Medium	1084	$255.00
Size Large	1085	$255.00
Pro-Kool Nomex Shirt, High Performance		
Size Medium	1072	$483.96
Size Large	1073	$483.96
Portable Cooling Unit, CD2 Type		
5 Speed, Universal Harness	1167	$809.91
2 Speed, Universal Harness	1002	$809.91
Ice Bottles, CD2 Type		
without Connector Lids	1008	$15.60
Ice Bottle Caps		
with Connectors	1089	$36.00
Fast Charger, (Battery charger)	1004	$122.40
Batteries, 9.6 V, 1700 mAh NiCd	1003	$105.50

Repair Kits for Garments & Cooling Units	1025	$125.00
Coolant Filters, Spares Package of 5	1090	$25.00

Source of Supply: Exotemp Ltd. Telephone: (613) 735-3996
320 Boundary Road FAX: (613) 735-3814
RR #4, Pembroke, Ontario
CANADA, K8A 6W5

ANNEX B

DRAFT MODIFICATION INSTRUCTIONS

MODIFICATIONS NECESSARY
TO INTEGRATE EXOTEMP PERSONNEL COOLING SYSTEM
WITH THE LAND FORCES CHEMICAL DEFENCE COVERALL

PURPOSE

1. To allow liquid cooling lines to pass through the Land Forces CW Protective Coverall.

WHEN MODIFICATION SHALL BE EMBODIED

2. Upon receipt

INSTALLATIONS AFFECTED

3. N/A

EQUIPMENT AFFECTED

4. Coverall - CW Protective
8415-21-860-7985

TRAINING AIDS AFFECTED

5. As required

BY WHOM WORK WILL BE PERFORMED

6. Operating Units.

RESOURCES REQUIRED

7. a. Manpower - SS Tech (531) - 2 manhours

   b. Down Time - N/A

   c. Material -

ITEM	STOCK NO.	PART NO.	DESCRIPTION	QTY
1.	8310-21-845-9894	UT-295D	thread, nylon OD Size E	AR
2.	Note 1		CD outer garment material	12"X12"
3.	Note 2	N-06408-47	tubing, Tygon 1/4"OD X1/8"ID	10"
4.	Note 3	PMC 17-02	connector, cooling female	ea. 2
5.	Note 3	PMC 22-02	connector, cooling male	ea. 2
6.	4020-21-807-0588		#8 linen cord	AR

NOTE

1. Item available from DCIEM/MLSD (416) 635-2051

2. Item available from Cole Parmer Inter. 7425 North Oak Park Ave., Chicago, Illinois, 60648, USA (312) 647-7600

3. Item available from Exotemp Ltd., 320 Boundary Road, Pembroke Ont. (613) 735-3996

MATERIEL RENDERED SURPLUS

8. Nil

MODIFICATION OF SPARE ITEMS

9. Nil

MODIFICATION EMBODIMENT PROCEDURES

10. The following is the sequence of operation:

a. Open Seam 3" on left side of CW coverall, 4" below front left lower shoulder strap attachment point;

b. Manufacture pass through using two pieces of material as per Figure B-1. Sew a double folded edge on the large end of both pieces. With outsides together, sew both pieces together. **Note** Leave 1/2" seam allowance on the narrow end (Figure B-2);

c. Install in opened seam creating a trunk for cooling lines to pass through. Close the remaining seam of the suit;

d. Cut 2 lengths of Tygon tubing 5" long and install a male and female connector onto each end, and;

e. Install both cooling lines in the trunk. Hand sew the seam with #8 cord completely closing the trunk (Figure B-3).

WEIGHT, BALANCE AND STABILITY DATA

11. This modification has no effect on weight, balance and stability

RECORDING PROCEDURES

12. N/A

REPORTING PROCEDURES

13. N/A

FUNCTIONAL CHARACTERISTICS OF EQUIPMENT ALTERED

14. No functional change

ANNOTATION TO APPLICABLE TECHNICAL ORDERS

15. Nil

ADDITIONAL INFORMATION

16. Nil.

REFERENCES AND OTHER DATA

17. Nil

EXCISED STUFF:

ANNEX C

ANCILLARY DATA

This Annex contains experimental data that supplements that provided in the body of the report.

Figures C-1 — C-3 provide detailed individual temperature vs time records for dry-bulb, wet-bulb, and globe temperatures recorded near the engine room control console (upper panel) and over the engine flats (lower panel) during the three days of the study. Data were logged at 5-minute intervals on a recording WBGT meter (see main body of report for details).

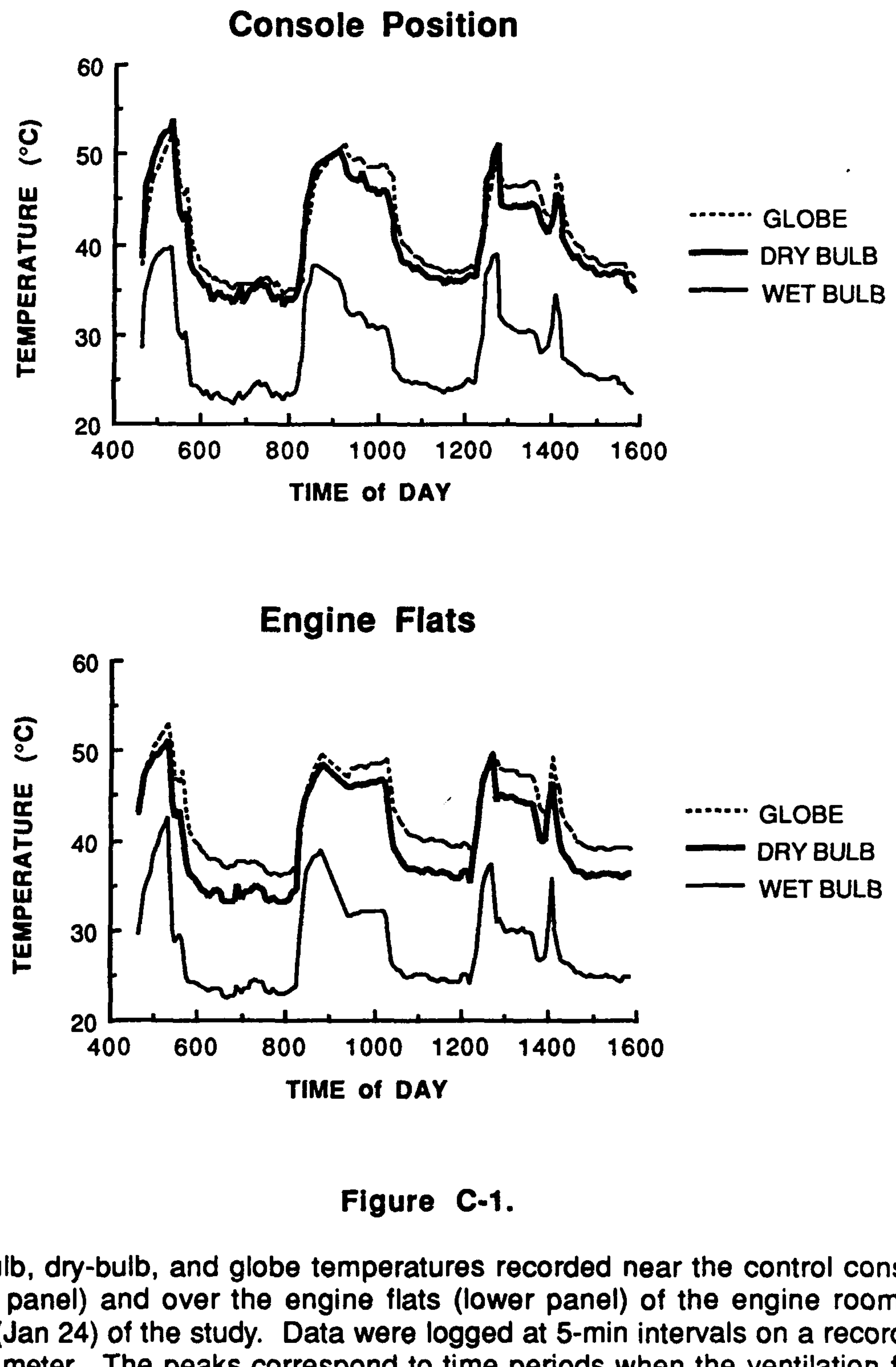


Figure C-1.

Wet-bulb, dry-bulb, and globe temperatures recorded near the control console (upper panel) and over the engine flats (lower panel) of the engine room on Day 1 (Jan 24) of the study. Data were logged at 5-min intervals on a recording WBGT meter. The peaks correspond to time periods when the ventilation fans were turned off (about 90 minutes duration at the beginning of each watch).

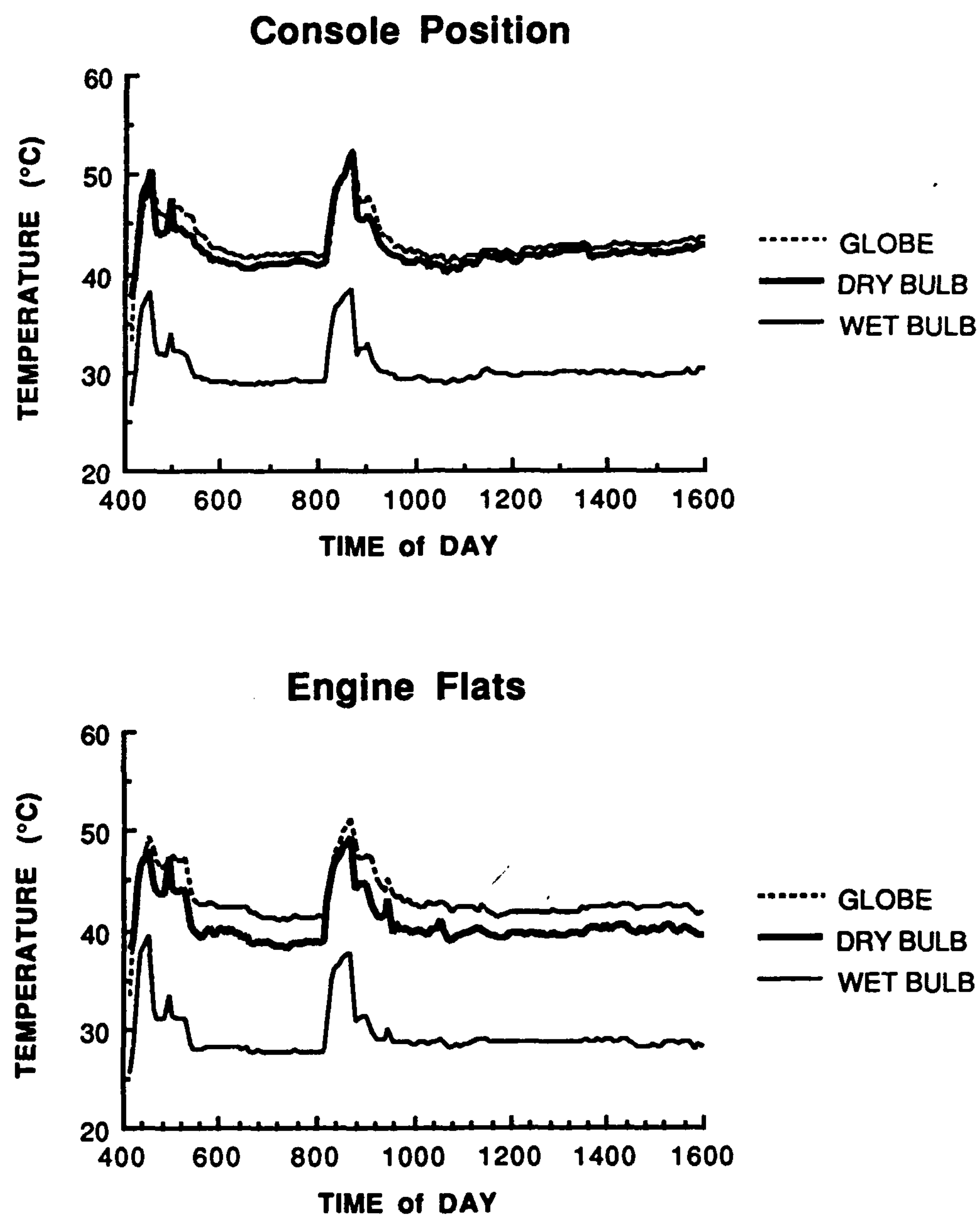
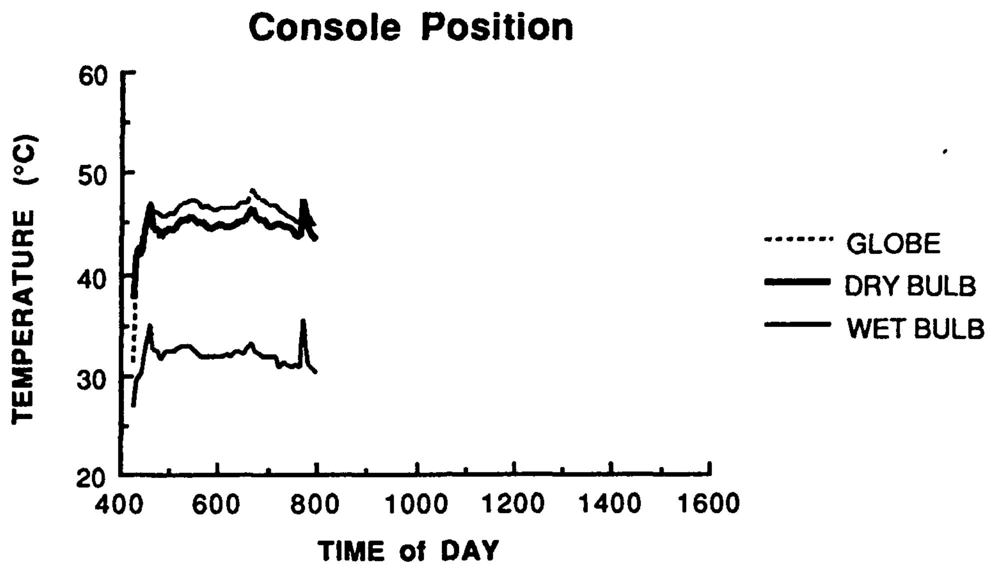


Figure C-2.

Wet-bulb, dry-bulb, and globe temperatures recorded near the control console (upper panel) and over the engine flats (lower panel) of the engine room on Day 2 (Jan 25) of the study. Data were logged at 5-min intervals on a recording WBGT meter. The peaks correspond to time periods when the ventilation fans were turned off (about 90 minutes duration at the beginning of each watch).



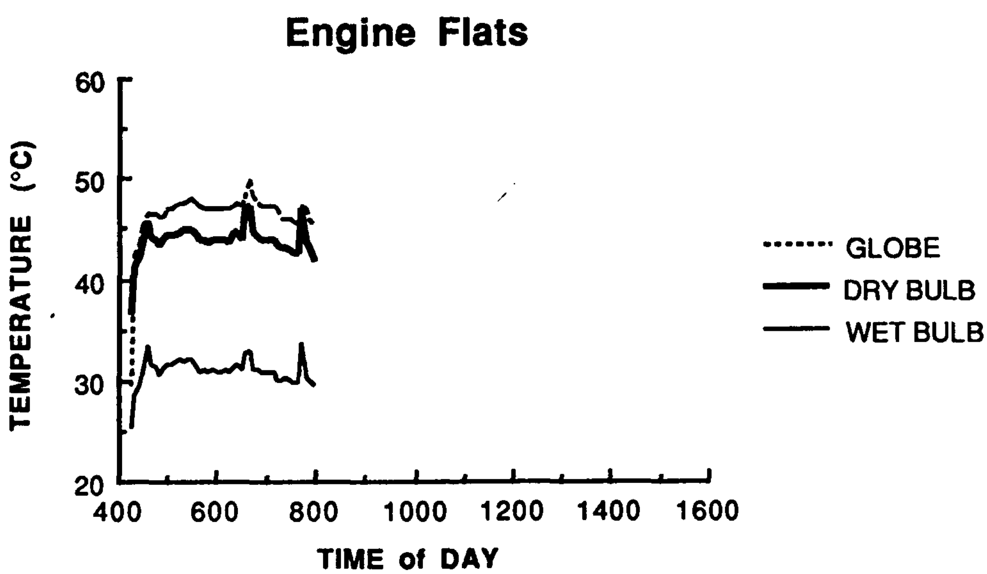


Figure C-3.

Wet-bulb, dry-bulb, and globe temperatures recorded near the control console (upper panel) and over the engine flats (lower panel) of the engine room on Day 3 (Jan 26) of the study. Data were logged at 5-min intervals on a recording WBGT meter. Only one watch period was available this day due to early arrival in port.

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The engineering spaces aboard Canadian Forces (CF) ships operating in warm climates can become very hot working environments. Some of these areas, notably the boiler room, are outside the citadel, and personnel working in these areas during periods of chemical threat must wear chemical defence (CD) clothing. The extra insulation and the increased resistance to sweat evaporation of this clothing, coupled with the heat of the environment, can impose a severe heat stress on the engineering personnel. A field trial was conducted aboard the HMCS Ottawa while en route from Halifax to Puerto Rico to see if the Exotemp liquid-based personal cooling system, proven very successful in CF Sea King helicopter operations in the Persian Gulf, could alleviate thermal stress under the above simulated conditions. Twelve engine room personnel from three watches participated in the trial, conducting their normal engine-room duties while being monitored for thermal physiological strain in four clothing ensembles: normal work dress (**WD**); normal work dress with cooling (**WC**); chemical defence clothing (**CD**); and chemical defence clothing with cooling (**CC**). Note that the engine room was used in place of the boiler room because it offered more space, and because the environment was easier to control. Heat stress conditions of 45-50°C dry-bulb temperature were created by shutting off the ventilation fans for about 90 minutes at the start of each watch. Rectal temperatures at 90 minutes of elapsed time clearly indicated statistically significant benefits of cooling with the chemical defence clothing (condition **CD**: 38.3°C; condition **CC**: 37.6°C; $p=0.002$). Although not statistically significant, reductions in core temperature were also seen when cooling was used with normal work dress (condition **WD**: 38.0°C; condition **WC**: 37.7°C; $p=0.053$). Heart rates were generally above 120 bpm without cooling (conditions **WD** and **CD**) while they generally remained below 120 bpm with cooling (conditions **WC** and **CC**). Limited skin temperature and heat flux information corroborated the core temperature and heart rate data, showing that the Exotemp personal cooling system can alleviate thermal strain in engineering space personnel. Personal cooling is recommended in conjunction with the CD ensemble, and could be considered for routine use with standard dress whenever ships are operating in hot climates.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible, keywords should be selected from a published thesaurus, e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

Heat Stress, Thermal Strain, Personal Cooling, Chemical Defence Clothing